# DEVICE AND METHOD OF CORRECTING EXPOSURE DEFECTS IN PHOTOLITHOGRAPHY

## Related Applications

**[0001]** This application is a continuation of, and hereby claims priority to and incorporates by reference in its entirety co-pending U.S. Patent Application 09/332,856, filed June 14, 1999, and entitled "DEVICE AND METHOD OF CORRECTING EXPOSURE DEFECTS IN PHOTOLITHOGRAPHY."

## Background of the Invention

### Field of the Invention

**[0002]** The invention relates generally to the correction of exposure variations in an optical system. More particularly, this invention relates to correcting variations introduced by one or more components, such as a reticle or pellicle, into the exposure field of the optical system.

### Description of the Related Art

**[0003]** Optical systems are widely used in the microelectronics industry to manufacture semiconductor wafers by a process known as photolithography. Typically, a photolithography system comprises a light source configured to project light rays to a condenser lens. The condenser lens collimates the light rays towards a pellicle placed before (or after) a reticle. Typically, the reticle is an optically clear quartz substrate having a chrome pattern used to project an image onto a portion of a photoresist-coated wafer. The pellicle is a very thin, transparent film which seals off the reticle surface from airborne particulates and other forms of contamination. A projection lens is placed after the reticle to receive and focus the light rays onto an exposure field on the wafer.

**[0004]** In designing such an optical system, any one of these components may be vulnerable to manufacturing imperfections which, even if minutely small, may cause intolerable or unacceptable defects in the photoresist layer of the wafer. For example,

aberrations due to defects in one or more lenses may include distortion, curvature of field, spherical aberration, and astigmatism. Moreover, distortions may be due to defects in the reticle that may be caused during manufacturing. For example, reticle defects may arise from impurities in the chrome, lack of adhesion of the chrome to the reticle, variances in ion beam used to produce chrome etching, or other similar defects. Reticle defects may cause intolerable or unacceptable variations in critical dimensions (CD's) in the exposure field. A CD represents the width or space of critical elements in an integrated circuit (IC).

**[0005]** Several attempts were made in the industry to compensate for general defects in the optical system. For example, in U.S. Patent No. 5,640,233 issued to McArthur et al., a two-plate corrector is disclosed in a stepper configuration so that an image from a reticle plane is projected to an ideal image at an object plane. Based on the premise that depth of field correction made at the reticle plane induces insignificant distortion, McArthur describes placement of the two-plate corrector at the reticle plane to correct depth of field distortions caused by the lens system. However, McArthur does not describe how to correct defects resulting from specific components, such as the reticle or pellicle.

**[0006]** To eliminate undesirable variances that result from defects in the reticle, some manufacturers simply replace the defective reticle with a new reticle. Other manufacturers resort to discarding wafers having intolerable CD's caused by the defective reticle. In either case, a significant increase in manufacturing cost due to reticle defects has become unavoidable.

**[0007]** Therefore, there is a need in the industry to compensate for individual component defects without having to replace the component or discard any defective wafers resulting therefrom. The solution of correcting such defects should be cost-effective and easy to implement.

## Summary of the Invention

**[0008]** To overcome the above-mentioned limitations, the invention provides a photolithography system having a light source configured to project light onto an object. The system comprises a reticle positioned to receive the projected light from the light source, wherein the reticle includes a defect. The system further comprises a filter positioned

between the light source and the reticle. The filter has a corrective element that is geometrically related to the location of and configured to substantially correct the defect in the reticle. In another embodiment, the photolithography system comprises a reticle positioned at a reticle distance from the light source to receive light therefrom, wherein the reticle includes a defect. The system further comprises a filter positioned at a filter distance from the light source that is greater than the reticle distance. The filter is configured to receive light passing through the reticle. The filter has a corrective element that is geometrically related to the location of and configured to substantially correct the defect in the reticle.

**[0009]** In another embodiment, the invention provides a reticle configured for use in a photolithography system. The reticle comprises a first plate having a predetermined pattern which includes a defect for projection onto an exposure field. The reticle further comprises a second plate attached to the first plate. The second plate comprises a filter having a corrective element that is geometrically related to the location of and configured to substantially correct the defect in the first plate. The invention also provides a method of correcting a defect in the reticle of the photolithography system. The method comprises the step of obtaining at least one measurement of a feature in an exposed image. The method further comprises the step of analyzing the measurement in connection with an expected feature in the exposed image. The method further comprises the step of determining the optical characteristics of a filter based on the analyzing step, the filter being suitable for substantially correcting the defect in the reticle.

## Brief Description of the Drawings

**[0010]** The above and other aspects, features and advantages of the invention will be better understood by referring to the following detailed description, which should be read in conjunction with the accompanying drawings, in which:

**[0011]** Figure 1 is a schematic diagram showing a typical optical system having a defective reticle.

**[0012]** Figure 2 is a schematic diagram of the optical system of Figure 1 having the corrective filter in accordance with the invention.

[0013] Figure 3 is a perspective view of one embodiment of the corrective filter built in combination with a defective reticle.

[0014] Figure 4 is a flowchart describing the steps of determining the characteristics of the corrective filter of Figure 2.

[0015] Figure 5A is a ray diagram of a reticle having one or more defects.

[0016] Figure 5B is a ray diagram of the reticle of Figure 5A after correction by the corrective filter in accordance with the invention.

Detailed Description of the Preferred Embodiment

[0017] The following description is not to be taken in a limiting sense, but is made merely for the purpose of describing the general principles of the invention. The scope of the invention should be determined with reference to the claims.

[0018] Figure 1 is a schematic diagram showing typical physical components of an optical system having a defective reticle. A photolithography system 100 comprises a light source 110 configured to project light rays 112 to a condenser lens 120. The condenser lens 120 collimates the light rays towards a reticle 130 having a chrome pattern 132. As noted above, the reticle 130 may be an optically clear quartz substrate used to project an image onto a surface. The reticle 130 is often covered by a pellicle 140 to seal off the surface of the reticle 130 from airborne particulates and other forms of contamination. As further described below, contaminants may interfere with the optical characteristics of the reticle 130 and, hence, distort the projection of the pattern 132. The pellicle 140 is a very thin, transparent film which may not interfere with the optical characteristics of the reticle 130. The pellicle 140 may also reduce the frequency of cleaning and extend the life time of the reticle 130.

[0019] The pellicle 140 passes the light rays 112 to a lens system 150. Although only one lens is shown in Figure 1, the lens system 150 may comprise one or more optical lenses. The lens system 150 focuses the light rays 112 onto an exposure field, such as a photoresist layer 160. The photoresist layer 160 typically comprises a light-sensitive, substantially uniform, and thin film spread on a wafer 170. A desired pattern may be formed

by exposing the photoresist layer 160 to light that is masked with a predetermined pattern, e.g., the pattern 132 of the reticle 130.

**[0020]** As described above, when designing such an optical system, any one of these components may be subject to manufacturing imperfections. More particularly, pattern distortions may result from defects caused during manufacturing of the reticle 130 or pellicle 140. These defects may cause unacceptable variations in the pattern on the photoresist layer 160. For example, due to a defect in the reticle 130, a point A of the pattern 132 may be projected as A' at a location before its intended projected location on the photoresist layer 160. Similarly, a point B of the pattern 132 may be projected as B' at a location after its intended projected location on the photoresist layer 160. Accordingly, any point on the pattern 132 may deviate from its intended projected location due to a distortion in virtually any geometric direction of the three dimensional space. As noted above, any of these pattern distortions may vary the CD's in the wafer 170 to unacceptable levels, which include CD's that are bridged, relatively small, scummed, or other defects which are generally known for CD's in the art. Accordingly, it is desirable to correct these distortions without having to replace the reticle 130 and/or pellicle 140.

**[0021]** Figure 2 is a schematic diagram of the photolithography system 200 having a corrective filter 210 in accordance with the invention. In one embodiment, the corrective filter 210 may be placed at any position between the light source 110 and reticle 130, as shown in Figure 2. In another embodiment, the corrective filter 210 may be placed between the reticle 130 and photoresist layer 160, i.e., after the reticle 130. It is desirable to place the corrective filter 210 at a location that does not interfere with heat dissipation characteristics of the lens system 150. In some applications, the lens system 150 may heat up due to energy emanating from the light rays. Typically, the rise in temperature of the lens system 150 affects its optical properties and, consequently, causes a distorted projection of light onto the photoresist layer 160. To compensate for such optical distortion, the lens system 150 is often controlled by an optical algorithm 220 which adjusts the optical properties of the lens system 150 as a function of temperature. Placing an object within a close proximity of the lens system 150 may interfere with its heat dissipation characteristics and cause the optical algorithm to erroneously compensate for heat variations. The distance

between the lens system 150 and reticle 130 varies from one photolithography system to another and, generally, is about 3-4 inches. Thus, it is desirable to place the corrective filter 210 at a minimum distance of about 1 inch from the lens system 150. However, if the machinery or robotic equipment that places the corrective filter 210 is configurable to such distances, other distances may be acceptable so long as interference with heat dissipation characteristics of the lens system 150 is tolerable.

[0022] In another embodiment, the corrective filter 210 may be designed for placement in close proximity to, or manufactured in combination with, the reticle 130. For example, the pellicle 140 may be designed to have the corrective properties of the corrective filter 210 for attachment to the reticle 130. Alternatively, the corrective filter 210 may be designed separately from the pellicle 140 and attached to the reticle 130 to form a substantially coherent unit. In such an embodiment, the reticle 130 effectively comprises a first plate that contains the predetermined pattern and a second plate attached to the first plate. Thus, the second plate includes the corrective filter 210. As demonstrated by these examples, there may be several design variations and locations of the corrective filter 210 which will become apparent to one of ordinary skill in the art from this description.

[0023] With the corrective filter 210 positioned between the condenser lens 120 and reticle 130, the reticle 130 correctly projects the pattern 132 onto the photoresist layer 160. More particularly, the corrective filter 210 compensates for any variation in substantially all the points of the pattern 132. For example, the corrective filter 210 corrects the projection of the point A of the pattern 132 so that its projection A' is located at the intended position on the photoresist layer 160. Similarly, the point B of the pattern 132 is corrected so that its projection B' is located at the intended position on the photoresist layer 160. As illustrated by the projection of the two points A and B, the corrective filter 210 corrects substantially all forms of optical distortions including reticle and pellicle defects due to myopia, hyperopia, and astigmatism.

[0024] Figure 3 is a perspective view of one embodiment of the corrective filter 210 built in combination with a defective reticle 130. As noted above, the corrective filter 210 may be attached to the reticle 130 so as to substantially form a coherent unit. In one embodiment, the corrective filter 210 may be designed to take over the functions of the

pellicle 140, thereby protecting the surface of the reticle 130 from airborne particulates and other forms of contamination. In another embodiment, the corrective filter 210 may, in addition to the pellicle 140, be attached to the reticle 130. Moreover, depending on the application, the corrective filter 210 may be attached anterior or posterior to the reticle 130.

**[0025]** Although a rectangular shape is shown for the corrective filter 210 in Figure 3, it will be understood that the geometric shape of the corrective filter 210 may be customized to fit virtually any desired dimensions and shapes suitable for the photolithography system 200. For example, the corrective filter 210 may have a shape that is a square, oval, elliptical, polygonal, trapezoidal, and other similar geometric shapes. The corrective filter 210 may comprise any material commonly used to manufacture optical filters in the art, such as fused silica or calcium fluoride. Given the optical characteristics of the corrective filter 210, one of several techniques may be employed to manufacture the corrective filter 210. These techniques include diamond milling, ion-milling, and mechanical polishing.

**[0026]** Figure 4 is a flowchart describing the steps of determining the optical properties of the corrective filter of Figure 2. To determine the optical properties of the corrective filter 210, the following method may be followed. At block 410, the wafer 170 is exposed to the light source, as illustrated in Figure 1. Generally, it is desirable to include a lens system to compensate for the reticle's magnification (or reduction) effect on the exposed image. In some cases, e.g., if the reticle has no significant distortion on the dimension of the image, it may be unnecessary to include a lens system when exposing the wafer to the light source. A measuring instrument, such as a scanning electron microscope model number 7830SI manufactured by KLA or 8100XP manufactured by OPAL, measures one or more image features in the projected pattern on the photoresist layer 160 (block 420). Some of the measured features may include positional offsets, distances between lines and spaces, line CD's, and contact related features. The lines may be produced by the pattern 132 in an isolated (e.g., a single line) or dense (e.g., a group of multiple lines) form in the exposure field. The measurements may be taken in the horizontal, vertical, sagittal, and/or tangential geometric planes. Depending on the microscope, the measurements may be taken with varying degrees of resolution, which is often expressed in picture element (pixel) per unit

area (e.g., inch) or pixel density. As is well known in the art, as the resolution increases, the finer and more detailed are the measurements. Hence, if desired, the resolution may be selectively increased to improve the accuracy of correction. More particularly, for fine (e.g., smaller CDs) reticle regions the resolution of measurement may be selectively increased. Similarly, for coarse (e.g., larger CDs) reticle regions the resolution of measurement may be selectively decreased. Hence, the type of measurements may vary to accommodate various regions of the same reticle 130.

**[0027]** The measurements may be stored in a computer memory, such as a hard disk, for further processing (block 430). Programmed with proper instructions, the computer analyzes the measurements to determine the distortions or errors across the exposure field (block 440). For example, based on the geometric difference between measured and expected projected point features, such as point size and positional offset, the computer determines the optical deviation (i.e., offset) of the projected image from that expected by a defect-free reticle. The instructions may be programmed using any computer language used in the art, such as C, Fortran, or other similar languages. Alternatively, a dedicated processor having instructions in the form of firmware may be used to implement this method. In either case, based on the calculated offsets for all measured pixels, the computer determines the optical correction characteristics of the corrective filter 210 (block 450).

**[0028]** Figure 5A is a ray diagram of light rays passing through the reticle 130 having one or more defects. As shown in Figure 5A, the reticle 130 typically includes a pattern 132 that causes a desired pattern to be projected in the exposure field on the wafer 170 (not shown in this figure). As noted above, as light rays 520 pass through the reticle 130, a defect in the reticle 130 causes a defect in the pattern of the exposed image. For example, the defect may comprise regions 510a and 511a that are unacceptably narrow or small. The defective regions 510a and 511a may be caused by an excess overflow of the layer of the pattern 132. If left uncorrected, the regions 510a and 511a cause unacceptable defects (e.g., CD variations) in the exposure field of the wafer 170.

**[0029]** Accordingly, Figure 5B shows a ray diagram of light rays passing through the reticle 130 after correction by the corrective filter 210 in accordance with the invention. In this embodiment, the corrective filter 210 is placed after the reticle 130, i.e., at a distance

from the light source 110 (not shown in this figure) that is greater than the distance between the reticle 130 and the light source 110. It is desirable to position and, more particularly, align the corrective filter 210 so as to cause light rays received from the defective regions 510a and 511a to diverge, thereby widening the defective regions 510a and 511a to regions 510b and 511b, respectively. Thus, the corrective filter 210 includes corrective elements having optically divergent properties, such as one or more divergent lens-like regions 510b and 511b that are optically aligned to respectively correct the defective regions 510a and 511a to the same or various degree of divergence. In other embodiments, the corrective filter 210 may include one or more convergent lens-like regions (not shown in this figure) that are optically aligned with defective reticle regions requiring same or various degrees of convergence. Additionally, the corrective filter 210 may include one or more regions 515b having a substantially small or no optical effect on light rays received from reticle regions that are not defective, or having only minor defects, e.g., the region 515a.

**[0030]** Therefore, with its convergent and divergent optical properties, the corrective filter 210 may correct virtually all forms of reticle defects, including deviations in the pattern 132 due to an absence of or excess in pattern material (e.g., chrome). Moreover, the corrective filter 210 may correct defects arising from the lens system 150, or from any other source in the photolithography system 100. Accordingly, in some applications, the corrective filter 210 may compensate for defects without having to determine the exact source of the defect.

**[0031]** In view of the foregoing, it will be appreciated that the invention overcomes the long-standing need for a correction filter and method of correcting defects in individual components of an optical system, such as the reticle. The invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiment is to be considered in all respects only illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather by the foregoing description. All changes which fall within the meaning and range of equivalency of the claims are to be embraced within their scope.